On the Origin of Cosmic X-Rays†

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Penzias and Wilson[1] have recently obtained evidence for a background radiation temperature of $3.5 \pm 1.0\ ^{\circ}K$ at 4080 Mc/s. If the measured radiation comes from a universal thermodynamic radiation field at this temperature, the corresponding energy density is $\sim 10^{-12}$ erg cm^{-3}, about a hundred times the intergalactic energy density of starlight. Such a high radiation density must have an important application to the problem of the inverse Compton effect, suggested by Felten and Morrison[2] as the source of cosmic x-rays and γ-rays.

The energy loss rate from relativistic electrons due to the inverse Compton effect is related in a simple way to the synchrotron energy loss rate, by

$$\frac{\text{Inverse Compton Loss Rate}}{\text{Synchrotron Loss Rate}} \approx \frac{\text{Energy Density of Radiation Field}}{H^2/4\pi},$$

where H is the magnetic intensity. Since a considerable amount of information is already available concerning synchrotron emission in the Galaxy and in radio sources, this relation can be used to estimate the importance of the

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inverse Compton effect. The latter is equivalent to synchrotron radiation (so far as energy emission rates are concerned) in an 'effective magnetic field' of intensity $2\pi^{\frac{1}{2}}$ (Energy Density of Radiation Field)$^{\frac{1}{2}}$. With $\sim 10^{-12}$ erg cm^{-3} for the energy density, the equivalent field has intensity $\sim 3 \times 10^{-6}$ gauss. This is probably comparable with the magnetic field in the Galaxy and in many extragalactic radio sources. It follows that the inverse Compton radiation arising from the background discovered by Penzias and Wilson should probably be as strong in many cases as the synchrotron radiation.

Consider next the frequency that the inverse Compton radiation is likely to have. For a temperature of 3.5 $^{\circ}$K the maximum of the Planck distribution is at $\sim 10^{7}$ Å, and the average quantum energy $\sim 10^{-3}$ eV. After scattering by a relativistic electron of energy γmc^2 such a quantum acquires energy $\sim 10^{-3}\,\gamma^2$ eV. Since the electrons in radio sources are believed to have typical energies of ~ 1 BeV, i.e., $\gamma \approx 2000$, the resulting quantum energies fall in the region of the observations of Giacconi, Gursky, Paolini, and Rossi,[3] and of Bowyer, Byram, Chubb, and Friedmann,[4] i.e., at ~ 3 Å.

Emission of x-rays by a typical radio galaxy should be of order 10^{43} to 10^{44} erg sec^{-1}. A system such as Cygnus A, lying at a distance of $\sim 5 \times 10^{26}$ cm, would give an x-ray flux at the Earth of order 10^{-10} erg cm^{-2} sec^{-1}, showing that strong extragalactic radio sources could also be x-ray sources near the present day limit of detectability. Emission of x-rays by the Galaxy should be comparable with the radio emission, $\sim 10^{38}$ erg sec^{-1}, giving a flux of $\sim 10^{38}\,(4\pi\, d^2)^{-1}$, where $d \approx 3 \times 10^{22}$ cm is the distance of the solar system from the galactic center. The flux should be $\sim 10^{-8}$ erg cm^{-2} sec^{-1}, comparable to the measured x-ray background.

The degradation time for an electron of initial energy γmc^2 due to synchrotron radiation is $\sim 10^{9}\,\gamma^{-1}\,H^{-2}$ sec. The degradation time due to the inverse Compton effect is obtained from this by setting $H = 3 \times 10^{-6}$ gauss, <u>viz</u> $10^{20}\gamma^{-1}$ sec, so that an electron with initial $\gamma \approx 2000$ is appreciably degraded in 5×10^{16} sec, less than the cosmological time scale of 3×10^{17} sec. Such electrons cannot survive in intergalactic space for more than about 10% of the ages of the galaxies. Since the universal energy density of x-rays cannot exceed $\sim 10^{-17}$ erg cm^{-3}, it follows that the electron energy density in intergalactic space cannot have been maintained as high as 10^{-17} erg cm^{-3} over the past 10^{10} years, and the likely inference is that the present energy density of electrons in intergalactic space is less than this.

Protons are degraded by the inverse Compton effect in a time scale $\sim 10^{20}\gamma^{-1}(m_p/m_e)^3$ sec, the initial proton energy being $\gamma m_p c^2$. This is $\sim 3 \times 10^{17}$ sec for $\gamma \approx 3 \times 10^{12}$, i.e., for protons of initial energy $> 10^{21}$ eV. Intergalactic protons are not degraded therefore up to the present limit of the observed energy spectrum.

References

1. A. A. Penzias and R. W. Wilson, Bell Telephone Laboratories Preprint (1965).
2. J. E. Felton and P. Morrison, Phys. Rev. Letters 10, 453 (1963).
3. R. Giacconi, H. Gursky, F. R. Paolini, and B. B. Rossi, Phys. Rev. Letters 9, 439 (1962).
4. S. Bowyer, E. T. Byram, T. A. Chubb, and H. Friedmann, Nature, 201, 1307 (1964).